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ScienceDirect

Green Energy & Environment xx (2017) 1–5

www.keaipublishing.com/gee

Feature article

Perspective of energy transfer from light energy into biological energy

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Received 10 November 2016; revised 16 November 2016; accepted 16 November 2016

Available online ■ ■ ■

Abstract

Energy has always been the most concerned topic in the world due to the large consumption. Various types of energy have been exploited and developed to enhance the output amount so that high requirements can be met. Like the hydro-energy, wind energy, and tidal energy, light energy as a renewable, clean, and widespread energy can be easily harvested. In microcosmic scale, some specific proteins and enzymes in green plants and bacteria play an important role in light harvest and energy conversion via photosynthesis. Inspired by the biomimetic sparks, these bioactive macromolecules and some artificially synthetic unites have been integrated together to improve the light-harvesting, and enhance their utilization efficiency. In this feature article, we primarily discuss that how to create the bio-inorganic hybrid energy converted system via biomimetic assembly strategy and artificially achieve the transformation from light into bioenergy, meanwhile highlight some promising works.

Keywords: Biomimetic; Molecular assembly; Energy conversion; Light; Bioenergy

1. Introduction

The sunlight as a green energy provides us with an inexhaustible power source, and interestingly inspired the design of light-responsive materials and the newly sustainable energy strategy [1,2]. For a long time, many efforts have been devoted to transfer light energy artificially into biological energy, further convert to electronic power or mechanical works for the creation of new-type energy sources [3,4]. This challenge has been currently appeared and faced to all the researchers coming from interdisciplinary sciences. Photophosphorylation is a classic prototype of light-to-bioenergy converter in chloroplast [5]. During this complex process, photosystem II (PSII) protein in chloroplasts can catalyze the oxidation of water, resulting in the generation of four protons, four electrons, and dioxygen in the aerobic condition [6–8]. These provided products can be directly utilized and enable the next energy conversion feasible as mechanical works, heat, and electronic energy, significantly providing the inspiration for the design of newly developed energetic materials and their applications [9–11].

Recently, substantial research works report that some artificially synthetic unites and biologically active components can be integrated together to assembly the biomimetic structures for the enhanced light harvest and further energy conversion. It shows that there will be a great potential in application [12–15]. Unlike the traditional light mediated devices, the natural chloroplasts exhibit strong preponderance in the light absorption and energetic transduction [16,17]. The natural components from biological entities also have glorious biocompatibility and high-efficiency biocatalytic property, significantly inspired the preparation of biohybrid materials. Some life-like light-mediated hybrid systems can be

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http://dx.doi.org/10.1016/j.gee.2016.11.005

constructed via introducing PSII proteins to perform the mimicking of chloroplasts for the generation of biological energy upon the light illumination [18]. To convert other types of energy from light, some special assembled elements have been employed, such as cytochrome oxidase, bacteriorhodopsin, and ATP synthase (ATPase). ATPase is a membrane-associated protein and widely exists in thylakoid membrane, which is responsible for the regulation of proton concentration [19,20]. The mechanical rotation of ATPase for ATP synthesis can be triggered in the presence of proton gradient. Inspired from this, several biohybrid systems *in vitro* have been assembled according to the actual benefit, and furthermore one can consider the construction of light-to-bioenergy converted device.

Here, we mainly talk about the perspective of energy transfer from light energy into biological energy. Bionic assembly of molecules has been proved as a bright strategy to construct functional structure. Some artificially synthetic unites and light-responsively bioactive macromolecules can be hybridized to form the light-to-bioenergy converted systems. This approach provides us with a novel assembled strategy for the construction of biomimetic devices, significantly demonstrate that how to enhance the energy utilization efficiency from light energy in microcosmic scale.

2. Assembled systems for the transformation from light into bioenergy

2.1. The conversion in nature from light to bioenergy

Photosynthesis is a fantastically physiological-biochemical process in the chloroplasts contented green plants and bacteria [21]. The solar light can be harvested during this process, and then is converted to the biological energy. Most of the nature systems alive in this way to obtain energy, which guarantees the power source requirement a continuous supplying for the organelles using in cellular level. Chloroplasts are the photosynthesizing organelles, and are much more efficient than any power systems made by human beings. As a power generated organelle that chloroplast performs a series of biochemical reaction and energy conversion. Many grana are organized together and encapsulated by the inner and outer membrane (Fig. 1a) to enhance the surface area to trap much more sun light. Several thylakoids are packed to form the stack-like structure (Fig. 1b), granum, which block plenty of the green chlorophyll molecules in the sacs as the solar power packs. The granum can be connected to the adjacent grana and immobilized to keep stable by the stroma lamellae. This smart skeleton can keep the all the sacs with a moderate distance and avoid overlapping and bunched together, which maximize the efficiency of chloroplasts to trap sun light [22].

Overview the complex process of photosynthesis, it can be divided into two stages, Calvin cycle and light reactions [23]. The carbon fixation occurs in the stroma of chloroplast accompany with energy consuming, which contain series cycles of many sugar molecules assembly by using carbon dioxide and productions of light reactions [24]. Unlike the Calvin cycle, light reaction occurs in the thylakoid, and carries out the biocatalytical photolysis of water to generate the oxygen and proton through the photosystems. The generated adenosine triphosphate (ATP) and NADPH can be utilized directly by the Calvin cycle. As compared with other organelles, chloroplast is the self-feeder that can make the consuming food for its own. The thylakoid membrane contains two classes of light-responsive proteins, photosystem I (PSI) and photosystem II (PSII) (Fig. 1c), which are in charge of the electron transfer and light-to-bioenergy transformation [25]. The water is split via the light mediated catalysis of PSII. The generated protons are encapsulated in the chamber of the thylakoids, and used to trigger the rotation of ATPase to synthesis ATP [26]. Thus, the light are transformed into the biological energy, further provide the possibility to the conversion of mechanical work and electric energy.

The photosystem of chloroplast as the one of most intelligent system made by nature, the researchers spend many efforts to investigate their working mechanism and introduce this inspiration to optimize the currently man-made light-to-energy converted devices. Such a bionic strategy offers the astounding and great potential to improve the efficiency of light harvest and further energy transformation, importantly pave a way to settle the mass utilization of fossil fuels.

2.2. In vitro assembly of artificial light-to-bioenergy converted devices

To simulate the natural photosynthesis, many efforts have been devoted by the interdisciplinary scientists to perform the separation of photosystem components from green plants and photosynthetic bacteria, such as PSI, PSII, ATPase, bacteriorhodopsin (BR), and deltarhodopsin (dR) [27–31]. However, how to integrate these biological unites with the synthesis devices to reconstruct a biomimetic platform that it is still a challenge. Molecular assembly of bionic inspired a new strategy to conjugate these light-responsive unites with the introduced components, subsequently achieve the hybridization of naturally biological macromolecules and their applications *in vitro*. As compared to the purely synthetic platforms, natural active components as assembled materials represent strong functionality and well biocompatibility [32–36]. Recent studies of natural biological hybrid with express pronounced performance at the energy conversion, especially light energy transform into the biological energy [37]. The introduced naturally assembled parts can significantly enhance the light harvest mass and further transferred efficiency, simultaneously achieve the desired "on/off" conversion by the open/close light source. Thus, the scientists pay more attention on the development of the light-driven bioenergy synthesis.

To assemble converted platform from light to bioenergy, several light-responsive unites have been introduced to reconstitute biomimetic devices. Moore and coworkers prepared a light-driven photosynthetic membrane for the ATP synthesis. This artificial membrane contains ATPase protein incorporated liposomal bilayer and proton-pumping